Dynamic Analysis of Land Cover in Four-Lake Area of Jianghan Plain Based on MODIS-EVI Time Series Data

JIN Wei-bin[1,2*], **XUE Lian**[2], **XIONG Qin-xue**[2]

1. College of Chemistry and Life Science, Huanggang Normal University, Huanggang 438000, China; 2. College of Agriculture, Yangtze University, Jingzhou 434025, China

Abstract According to the time series data of Enhanced Vegetation Index (EVI) in Four-Lake Area of Jianghan Plain during the period 2001 – 2007, we use Harmonic Analysis of Time Series (HANTS) to conduct cloud removing processing, and calculate the sum of square N of time series value of each pixel. The pixels with $N > 0.25$ are classified as vegetation coverage area; the pixels with $N < 0.25$ are classified as non-vegetation coverage area. As to vegetation coverage area, we use the second-order difference method to judge the frequency of peak value of EVI time series data. Within one year, the vegetation coverage area with peak value happening 1 time is woodland and grassland; the vegetation coverage area with peak value happening 2 times is arable land; the vegetation coverage area with peak value happening 3 times or more is vegetable land. Supervised classification method is used to identify cities, towns, water area in non-vegetation coverage area and woodland, grassland in vegetation coverage area. We draw the land cover classification diagram of Four-Lake Area in the period 2001 – 2007. In comparison with the land cover classification based on multitemporal ETM data in 2001, the difference of area of arable land is within 10%. Using MODIS – EVI data, we can rapidly and efficiently conduct land cover classification with low cost. The dynamic analysis results indicate that the area of arable land is in the process of declining, while the area of other cover types shows an increasing trend.

Key words Enhanced Vegetation Index (EVI), Land cover classification, Four-Lake Area of Jianghan Plain

Remote sensing information is the primary way to obtain considerable land cover classification and changes. The spectral performance, spatial resolution and data quality of MODIS sensor in the Terra satellite launched in 1999 was greatly improved. In the land monitoring and mapping on a global and regional scale, it has drawn the users and remote sensing researchers' attention[1]. In recent years, the MODIS products have also provided multitemporal Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) after data preprocessing, offering more convenient data basis for carrying out research on regional land cover classification and changes. Using MODIS – NDVI time series data, Lu Tingting *et al.*[2] extracted the information on the area of arable land in Thailand. Using MODIS – EVI time spectrum to track inherent phenological information, Zhang Xia *et al.* researched the land cover classification in the North China Plain. Using MODIS – EVI time series, Toshihiro *et al.*[5] analyzed the phenological characteristics of rice in the Vietnamese Mekong Delta, and produced five major rice growing pattern diagrams. Studies show that EVI has the stronger ability to identify crops than NDVI[6–8].

Therefore, it is entirely possible to use the EVI index to obtain high-precision macro land cover and information of land use classification, providing a convenient way for the extraction and monitoring of useful agricultural information, such as cropping pattern. However, in different places, in different years, due to differences in cropping system, spectral characteristics of varieties and meteorological conditions, the classification of critical periods, classification indicators and even classification methods are different[9–13]. Therefore, in terms of specific areas, how to use EVI time series data to judge land cover type (namely the classification strategy or decision tree rules) still needs to be further researched.

Four-Lake Area of Jianghan Plain is an important agricultural area of wetland in China. The studies on land cover and its change in Four-Lake Area have drawn wide public attention[14–16]. But previous studies are based on the TM data with high spatial resolution, and it is difficult to complete dynamic continuous monitoring. In this paper, based on the variability of EVI time series data, according to the cropping system and phenological characteristics, we set down the judgement rules of land cover classification in Four-Lake Area, and extract the land cover change information in this region during the period 2001 – 2007, in order to provide a reference for the case accumulation and classification rules when conducting land cover classification using EVI time series data.

1 The study area and data source

Four-Lake Area is located in the hinterland of Jianghan Plain in Hubei Province, named after four large lakes in the region (Sanhu Lake, Bailuhu Lake, Changhu Lake, Honghu Lake), and its geographical position is 111°57′ – 114°5′ E, 29°26′ – 31°2′ N. The region is studded with myriad lakes; all

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* Corresponding author. E-mail: wbjin@yangtzeu.edu.cn

levels of main stream and tributary are intertwined, with dense water network. The main limiting factor for agricultural production is the floods due to rain; in some years, the shortage of agricultural water in Spring also becomes an obstacle to aquaculture and farming.

The area includes the northern area of the Yangtze River in Jingzhou City, part of land in Jingmen and Qianjiang, with a total area of 12 000 km^2. The remote sensing data are from the MODIS data and MODIS standard data product classification system installed in the two satellites of TERRA and AQUA, constituted by five levels of data. MOD13 is the second-level data product on the land, and the content is rasterized normalized difference vegetation index and enhanced vegetation index (NDVI/EVI). In this study, we download the EVI time series values of each grid in two areas (H27V5 and H27V6) during the period 2001 – 2007 in MODIS data from Internet (https, // lpdaac. usgs. gov/lpdaac/get_ data/data_ pool), used for the identification of land cover change.

Data preprocessing includes the use of related function of ENVI software to realize image stitching, coordinate conversion, cutting. The image of Four-Lake Area is in the two areas of H27V5 and H27V6, and the satellite image downloaded is divided into two parts, so two sets of data obtained are stitched first; the image and information stitched contains all of regions in Four-Lake Area. In order to keep consistency of analysis, WGS84 geodetic datum and UTM49 projection are selected for all remote sensing and GIS data. The MASK function in ENVI software is used for cutting, to remove all redundant information. Using STACKING function, all EVI data are integrated in a file, forming a multitemporal database.

The Harmonic Analysis of Time Series (HANTS) is used to conduct cloud removing processing on the time spectral data. The core algorithm is the fitting of Fourier transformation and method of least square, namely breaking down the time spectrum data into a finite number of harmonic waves (sine or cosine wave), and then selecting several harmonic waves that can reflect time series characteristics of image to be superimposed, to reach the purpose of reconstructing time series data. The paper selects harmonic number as 3 to conduct curve smoothing.

2 Land cover classification method

The EVI value is the comprehensive reflection of the vegetation cover on the surface. In the non-vegetation coverage area, such as cities and towns, water body, EVI value is very small, and shows the smallest yearly variation; in the vegetation coverage area, EVI value is very big, and shows large yearly variation.

In order to increase the degree of difference, this study calculates the sum of square of EVI time series value, denoted by N, so that the difference in the total sum of the EVI value between pixels is enlarged. Through the analysis of distribution characteristics of N value of the junction point between land and water, we find that $N=0.25$ is the center value of distribution of the junction point between land and water. According to this, when $N<0.25$, it can be judged as non-vegetation coverage area; when $N>0.25$, it can be judged as vegetation coverage area.

For the non-vegetation coverage area, we use the supervised classification method to identify cities and towns, water body in advance, that is, determining the wave spectrum of cities and towns, water body, then completing the identification of cities and towns, water body, using the supervised classification function of ENVI software.

For the vegetation coverage area, we conduct re-classification according to the peak value of EVI time series value. The frequency of time series peak value is judged, using second-order difference method[17]. The steps are as follows:

Assuming that xi is the EVI time phase value of pixel during the year, $i=1,2,\cdots,23$, we define the following sequence:

$$s_1(i)\{x_{i+1}-x_i;\ i=1,\ 2,\ \cdots,\ 22\} \quad (1)$$

$$s_2(i)=\begin{cases}1 & s_1(i)>0\\ -1 & s_1(i)<0\end{cases}\ i=1,\ 2,\ \cdots,\ 22 \quad (2)$$

$$s_3(i)=\{s_2(i+1)-s_2(i);\ i=1,\ 2,\ \cdots,\ 21\} \quad (3)$$

It is not difficult for us to note that the sequence $s_3(i)$ has only three possible results: 2, −2, 0. The crest of EVI appears in the position of the sequence $s_3(i)$ with element of −2, front and rear elements of 0; the trough of EVI appears in the position of the sequence $s_3(i)$ with element of 2, front and rear elements of 0. Thus, we can judge the frequency of peak value of time series data of each pixel (denoted by F), and make a simple program to complete the judgment on the frequency of EVI peak value of each pixel (F).

According to the phenological characteristics of vegetation in the region, woodland and grassland complete a growth cycle within a year; EVI time series data show single-peak feature; the crops follow double cropping system, showing two-peak feature; the pixel with more than three peaks is in line with the characteristics of multiple cropping system of vegetables in the local areas.

So, within one year, the vegetation coverage area with peak value happening 1 time is woodland and grassland; the vegetation coverage area with peak value happening 2 times is arable land; the vegetation coverage area with peak value happening 3 times or more is vegetable land. Finally we conduct identification of woodland and grassland, and the method is also supervised classification, the same with that for the identification of cities and towns, water body. The block diagram of classification process of pixel is shown in Fig. 1.

3 Land cover classification results

3.1 Analysis of errors in land classification results Taking the multitemporal ETM supervised classification results in 2001 as the control, the error of the classification results of MODIS data is evaluated. Fig. 2 is the supervised classification results using the ETM data in 2001. The adopted data have eight time phases in total: May 10, 2001; May 19, 2001; July 10, 2001; July 22, 2001; September 15, 2001; September 24, 2001; December 29, 2001; January 5, 2002. The location includes Area 39, Area 40 in Track 123.

Based on this, we calculate the error rate of classification results using MODIS-EVI data, as is shown in Table 1. It can be seen from Table 1 that the error rate of the scattered land cover type with a small area is big (such as cities and towns, woodland, water body); the error rate of the concentrated land cover type with a big area is 10% or less, relatively accurate (such as arable land).

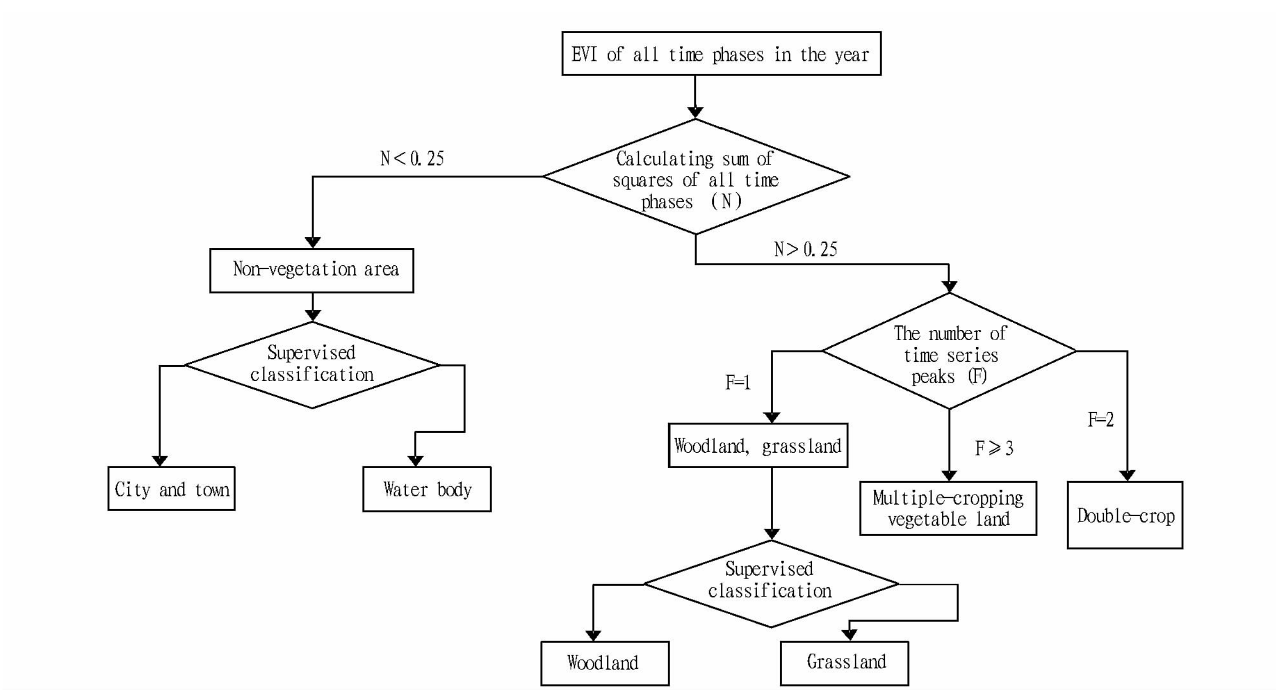

Fig. 1 Landscape terrain classification and discrimination diagram

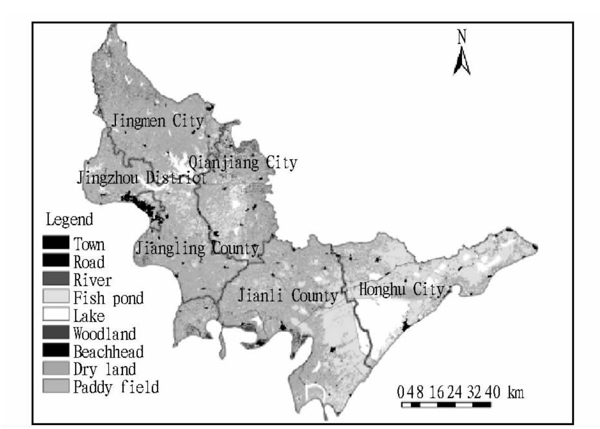

Fig. 2 The supervised classification results using the ETM data in Four-Lake Area in 2001

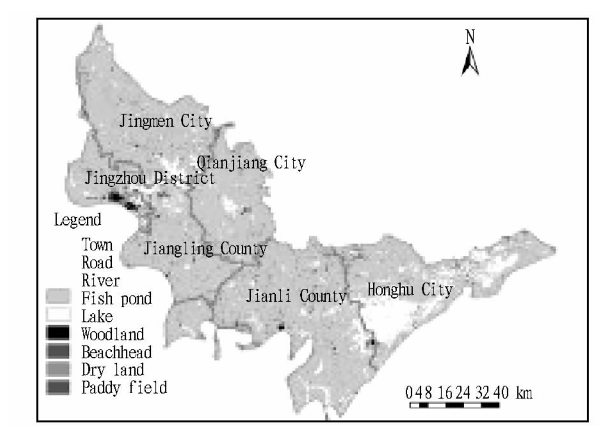

Fig. 3 Land cover in 2001

Table 1 Comparison between ETM satellite supervised classification results and MODIS data classification results in 2001

Land type	MODIS data	ETM data		Error rate
	Area/km^2	Corresponding type	Area/km^2	%
City and town	255.3	City and town	157.8	61.8
Water body	2 856.7	Rivers, farming areas, lakes	3 560.6	19.8
Vegetable land	326.2	None	–	–
Grassland	99.4	Grassland	153.0	35.0
Woodland	71.8	Woodland	152.3	52.9
Farmland	8 490.4	Dry land and paddy field	7 779.2	9.1

Note: Error rate = |MODIS − ETM|/ETM * 100%.

3.2 Dynamic analysis of land cover classification The land cover classification results in Four-Lake Area during the period 2001 – 2007 can be shown in Table 2 and Fig. 3 – 9. The results show that during the period 2001 – 2007, the land cover in Four-Lake Area changed constantly. The arable land experienced great change, whose area was reduced by 299.02 km^2 during the period 2001 – 2007; the area of water area, grassland, woodland increased by 219.57, 53.63, 42.20 km^2, respectively; the area of vegetable land decreased by 21.10 km^2; the area of land occupied by cities and towns increased by 4.73 km^2.

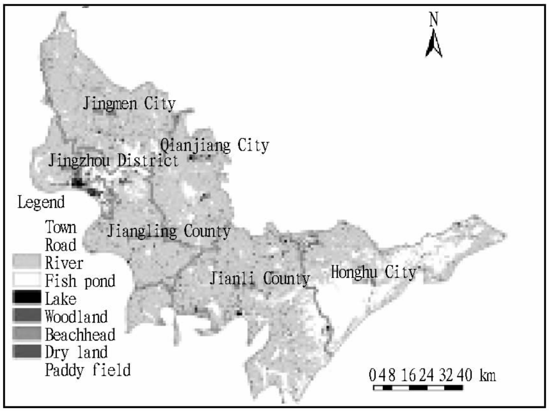

Fig. 4 Land cover in 2002

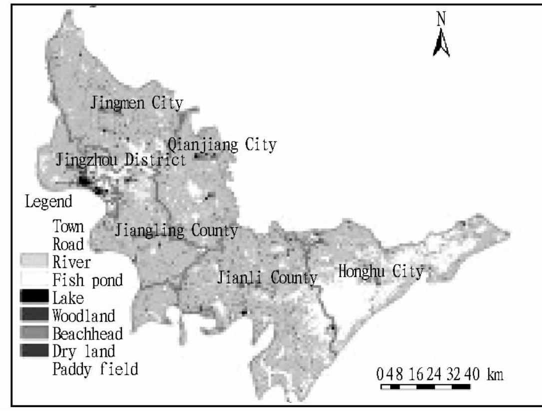

Fig. 5 Land cover in 2003

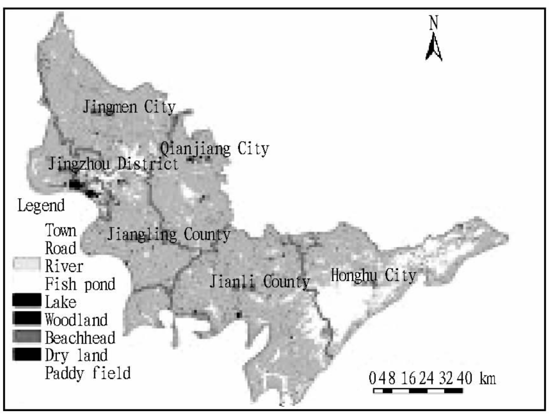

Fig. 6 Land cover in 2004

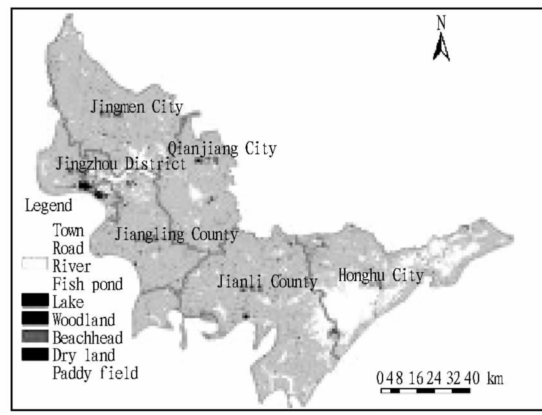

Fig. 7 Land cover in 2005

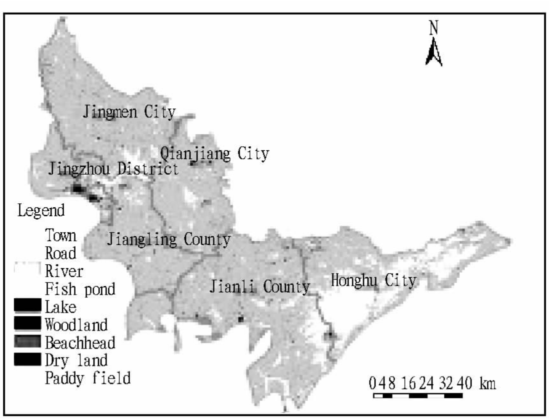

Fig. 8 Land cover in 2006

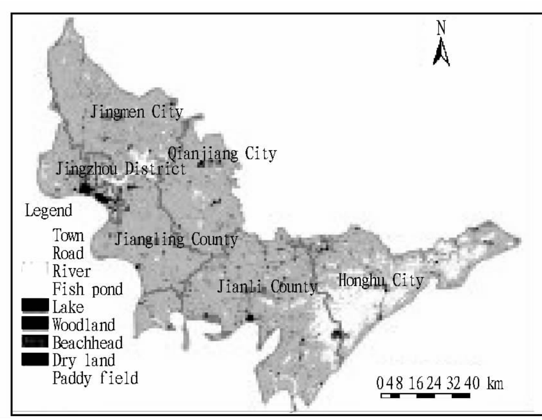

Fig. 9 Land cover in 2007

Table 2 Land cover change in Four-Lake Area during the period 2001 – 2007 Unit: km^2

Land type	2001	2002	2003	2004	2005	2006	2007
Farmland	8490.48	8514.91	8445.06	8446.67	8346.71	8297.00	8 191.46
Water area	2856.68	2812.39	2913.80	2908.49	2930.12	3013.87	3 076.25
City and town	255.27	244.70	220.16	232.40	260.43	268.26	260.00
Woodland	71.83	86.97	77.47	76.66	101.25	78.11	114.03
Grassland	99.37	109.95	128.90	110.64	124.82	142.75	153.00
Vegetable land	326.24	330.91	314.38	324.85	336.34	299.62	305.14
Total	120 99.87	12 099.83	12 099.77	12 099.71	12 099.67	12 099.61	12 099.88

4 Conclusions and discussions

According to the phenological characteristics of vegetation in Four-Lake Area, we set down the rules for the identification of ground object type in accordance with the EVI time series variability, and complete the dynamic classification of land cover in Four-Lake Area during the period 2001 –2007. The study shows that the area of arable land in Four-Lake Area is in the process of constant shrinking, while the area of cities and towns increases, indicating that this area is in the process of urbanization. The area of water body, woodland and grassland increases, indicating that the implementation of returning farmland to lakes, fishing and the development of forestry in recent years has achieved certain results, and the landscape ecological structure of the area takes a turn for the better. The resulting changes in the ecological environment are yet to be further studied.

The MODIS satellite revisit cycle is short, and the data acquisition is simple, without paying. The provided vegetation index data is given on the basis of completing several rounds of pretreatment. Based on the accuracy of land cover classification of MODIS satellite data, for a large area of arable land concentrated, it is acceptable[18], so it can be expected that the application of MODIS satellite data products will be increasingly frequent. The EVI data are updated quickly, so the results of this study can be used for the fast tracking and monitoring of land cover change in this area. Of course, the above classification rules have to go through necessary on-site verification, and the identification accuracy needs to be better evaluated and analyzed, so as to lay a solid foundation for giving full play to the role of remote sensing data resources.

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element of development of valley economy; sum up the mechanism and path of development of valley economy.

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